THE EFFECT OF TEMPERATURE ON HOSPITAL ADMISSIONS IN NINE CALIFORNIA COUNTIES

A Report From:
California Climate Change Center

Prepared By:
Rochelle Green, Rupa Basu, Brian Malig, Rachel Broadwin, Janice Kim, Bart Ostro

Office of Environmental Health Hazard Assessment, California Environmental Protection Agency

FINAL PAPER

Arnold Schwarzenegger, *Governor*

August 2009
CEC-500-2009-037-F

Acknowledgments

Supported by the California Energy Commission's Public Interest Energy Research (PIER) Program.

The opinions expressed in this article are solely those of the authors and do not represent the policy or position of the State of California or the California Environmental Protection Agency.

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts focus on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's PIER Program established the **California Climate Change Center** to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the center seeks to inform the public and expand dissemination of climate change information, thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

Table of Contents

List of Figures

List of Tables

Abstract

Elevated temperature has been associated with morbidity in the United States and other countries, however, no studies have focused on California, where humidity is generally lower than in other U.S. regions. This study examined the association between mean daily *apparent temperature* (which incorporates temperature and humidity) and hospital admissions for several diseases in nine California counties from May to September 1999–2005. Researchers conducted a time-stratified case-crossover study limited to cases with residential zip codes located within 10 kilometers of a temperature monitor, to minimize exposure misclassification. County-specific estimates were combined, using a random effects meta-analysis. The analyses also considered the effects of ozone and particulate matter ($PM_{2.5}$). A total of 852,619 hospital admissions were included. A 10°F increase in unlagged mean apparent temperature corresponded to a 3.5 percent increase in ischemic stroke, 2.0 percent increase in all respiratory diseases, 3.7 percent increase in pneumonia, 10.8 percent increase in dehydration, 3.1 percent increase in diabetes, and 7.4 percent increase in acute renal failure. Results showed a 22.8 percent increase in gastrointestinal infectious diseases among 5 to 18 year olds. No association was found between apparent temperature and admissions for all cardiovascular diseases. Controlling for air pollutants reduced the effect estimates for all respiratory disease but the effect of temperature on pneumonia remained elevated. None of the other outcomes was confounded by air pollution. Even without extremes in apparent temperature, an association was observed between temperature and hospital admissions. Reducing heat exposure through air conditioning use and mitigating heat effects through adequate hydration during hot weather are important steps in reducing heat-related morbidity.

Keywords: California, temperature, heat, hospital admissions, case-crossover, age

1.0 Introduction

Several studies around the world have documented a relationship between increased ambient temperature and mortality (Basu et al. 2005; Basu et al. 2008; Basu and Ostro 2008; Garssen et al. 2005; Kovats et al. 2006; Le Tertre et al. 2006; Stafoggia et al. 2006). Few studies have looked at morbidity, and there are none in California, where temperature and humidity are generally mild, but where pollution levels tend to be higher than in other areas of the United States. When people are exposed to excess heat, cardiac output is increased in order to shift blood flow to subcutaneous areas, which facilitates heat loss. If too much blood is diverted, there is increased stress on the heart and lungs. Excess heat has been associated with heat stroke, heat exhaustion (McGeehin and Mirabelli 2001) and acute renal failure (Semenza 1999). High temperatures increase blood viscosity and cholesterol. Physiological studies have suggested that the blood of heat-stressed individuals coagulates more readily (Keatinge et al. 1986). During the Chicago heat wave of 1995 there were increases in hospital visits for cardiovascular disease and other medical conditions (Semenza et al. 1999), including cardiovascular and respiratory diseases, diabetes, renal diseases, emphysema, and nervous system disorders. A study of the effect of temperature on hospital admissions for heart disease in general and myocardial infarction in particular in persons age 65 and older in 12 U.S. cities found an increase in hospital admissions for heart disease on the same day as, and the day before, admission with increased temperature (Schwartz et al. 2004).

Since hospital discharge data is available for the State of California, we have the opportunity to examine the effect of heat on hospital admissions for several outcomes in nine California counties between 1999 and 2005.

2.0 Methods

2.1. Hospital Admission Data

Daily hospital admissions data were obtained for nine California counties from the Office of Statewide Health Planning and Development (OSHPD), Healthcare Quality and Analysis Division, from May 1, 1999, through September 31, 2005 (OSHPD Patient Discharge Data [PDD], 1999–2005. Sacramento, California). All California hospitals, both public and private, are included in the OSHPD data set. The nine California counties included Contra Costa, Fresno, Kern, Los Angeles, Orange, Riverside, Sacramento, San Diego, and Santa Clara, which were the same nine used in an earlier investigation of temperature and mortality (Basu et al. 2008). The unit of observation for the analysis was the hospital admission; therefore a person could be included in the data set more than once. All hospital admissions in the nine counties during the study period were included in the study. We retrieved information on date of admission, primary admission diagnosis, county and zip code of residence, age, gender, and ethnicity. We examined hospital admissions for all cardiovascular diseases (International Classification of Diseases, 9th Revision [ICD-9] codes 390–459), ischemic heart disease (ICD-9 codes 410–414), acute myocardial infarction (ICD-9 code 410), heart failure (ICD-9 code 428), hemorrhagic stroke (ICD9 codes 430–432), ischemic stroke (ICD-9 codes 433–436), all respiratory diseases (ICD-9 codes 460–519), pneumonia (ICD-9 codes 480–486), asthma (ICD-9 code 493), chronic bronchitis or emphysema (COPD) (ICD-9 codes 491–493), diabetes (ICD-9 code 250), dehydration (ICD-9 code 276.5), heat stroke (ICD-9 code 992), intestinal infectious diseases (ICD-9 codes 001–009), and acute renal failure (ICD-9 code 584).

2.2. Weather Data

Weather data were obtained from monitors operated by the California Irrigation Management Information System (CIMIS) and the U.S. Environmental Protection Agency (U.S. EPA) for the study period. The CIMIS monitors reported daily mean, minimum, and maximum temperatures, while the U.S. EPA monitors recorded hourly data. For the U.S. EPA data, only those monitors that recorded at least 18 hours of daily observations were included for each county. Using ArcGIS Version 9.2,[1] we created circular buffers with a 10 kilometer radius around each monitor in the nine counties and selected hospitalized subjects for whom the geographic centroid of their residential zip code fell within the buffer of at least one monitor. If the zip code centroid was located within 10 kilometers of more than one monitor, the closest monitor was chosen. Mean daily apparent temperature in degrees Fahrenheit (°F) was calculated to incorporate temperature and relative humidity using a method that has been described previously (Basu et al. 2008). Our analysis was limited to the warm months (May through September).

2.3. Study Design and Data Analysis

We used the case-crossover approach for data analysis, a study design that inherently minimizes the effects of time trend and seasonality. The case-crossover study is a modification of the matched case-control study, in which each person serves as his or her own control; the temperature on the day of hospital admission (case period) is compared with temperature on different days when the hospital admission did not occur (referent periods). We used the time-stratified approach (Levy et al. 2001) to select referent periods every third day of the same month and the same year as the case period. In addition to a linear term for apparent temperature, day of the week was added to the model as an indicator variable. A unique identifier was created for each individual so that each case period could be matched with up to 10 referent periods for the same individual. We examined three lag times: a single day effect of same-day temperature exposure (lag 0); and single day effects of either one or two previous days of exposure (lag1, lag2). We also examined various cause-specific hospital admissions stratified by age, ethnicity and gender. Finally, we examined possible confounding by particulate matter ($PM_{2.5}$) and ozone by adding $PM_{2.5}$ to the basic model described above and by restricting the analysis to cases and their controls matched on ozone level within 4 parts per billion (ppb). All case-crossover analyses were conducted with SAS statistical software,[2] using the PHREG procedure[3] for conditional logistic regression. We first obtained county-specific effect estimates and then combined all nine county-specific estimates using a meta-analysis with a random effects model (Anderson et al. 2005; DerSimonian and Laird 1986). The meta-analyses

---

[1] Redlands, California: Environmental Systems Research Institute, 1995–2008

[2] SAS Institute, Cary, North Carolina

[3] The PHREG procedure performs regression analysis of survival data based on the Cox proportional hazards model.

were conducted using R (version 2.5.0 R Development Core Team (2006).[4] Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated per 10°F increases in mean daily apparent temperature. The results are presented as the percent change in hospital admission per 10°F using the following calculation: (OR - 1) X 100%.

3.0 Results

Our study population consisted of 853,096 hospital admissions with the above listed diagnoses and criteria. The mean apparent temperature on "case-days" for the study period ranged from 64.6°F (18.1°C) in Santa Clara County to 77.5°F (25.3°C) in Riverside County, while the mean difference in temperature between the "case-day" and "control-days" was highest in Fresno County (0.2°F) (Table 1). The number of hospital admissions ranged from 27,880 in Contra Costa County to 426,805 in Los Angeles County.

[4] R is a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. www.R-project.org.

Table 1. Environmental variables and number of hospital admissions in the study population in the nine California counties, May to September, 1999–2005

	Contra Costa	Fresno	Kern	Los Angeles	Orange	Riverside	Sacra-mento	San Diego	Santa Clara
Environmental variables									
Number of temperature monitors	5	14	9	15	3	14	7	10	2
Apparent temperature on "case-days" (°F)									
Mean	64.9	75.6	77.1	69.9	71.0	77.5	71.5	68.7	64.6
25th percentile	60.3	70.3	71.8	65.6	66.7	70.0	66.1	64.5	61.3
75th percentile	69.3	81.4	83.1	74.1	75.0	85.1	76.9	72.8	68.3
Difference of apparent temperature between "case-day" and "control-days" (°F)									
Mean	0.1	0.2	0.1	0.1	0.0	0.0	0.1	0.0	0.1
25th percentile`	-4.7	-6.2	-5.9	-3.6	-3.3	-5.4	-6.3	-3.4	-4.3
75th percentile	4.9	6.5	6.2	3.8	3.4	5.4	6.4	3.5	4.5
Ozone (max 1-hr) on "case-days" (ppb)									
Mean	51.8	82.9	81.6	63.9	56.4	84.5	64.1	54.7	44.2
25th percentile	41.9	69.6	71.0	52.7	48.3	72.3	53.3	48.4	35.6
75th percentile	59.7	95.8	92.7	73.2	62.8	97.0	73.8	60.5	49.7
Difference of ozone (max 1-hr) between "case-day" and "control-days" (ppb)									
Mean	-0.2	0.2	0.0	-1.0	-0.6	-0.5	-0.1	-0.3	-0.3
25th percentile	-12.3	-15.2	-12.6	-14.7	-11.0	-16.6	-13.1	-8.2	-10.3
75th percentile	12.0	15.5	12.6	12.8	9.8	15.6	13.0	7.7	9.6

Table 1. (continued)

	Contra Costa	Fresno	Kern	Los Angeles	Orange	Riverside	Sacra-mento	San Diego	Santa Clara
$PM_{2.5}$ on "case-days" ($\mu g/m^3$)									
Mean	6.9	10.9	13.2	19.0	14.6	25.6	9.1	12.8	10.7
25th percentile	4.6	7.7	10.3	14.3	11.0	16.5	6.0	9.9	7.0
75th percentile	8.4	13.0	15.2	22.1	17.4	32.0	10.9	15.1	12.9
Difference of $PM_{2.5}$ between "case-day" and "control-days" ($\mu g/m^3$)									
Mean	0.1	0.1	0.0	0.0	-0.2	0.0	0.0	0.1	0.1
25th percentile	-2.7	-3.0	-3.4	-5.6	-4.6	-9.2	-2.8	-3.3	-4.1
75th percentile	2.8	3.5	3.5	5.6	4.3	9.1	2.9	3.4	4.1
Pearson correlation between apparent temperature and ozone (max 1-hr)	0.55	0.67	0.75	0.45	0.25	0.48	0.65	0.09	0.50
Pearson correlation between apparent temperature and $PM_{2.5}$	0.18	0.44	0.39	0.15	0.17	0.04	0.28	0.18	0.41
Population under study									
Number of hospital admissions	27,880	43,417	34,610	426,805	68,681	54,260	63,463	105,167	28,813

In general, we found the highest effect estimates for the same day apparent temperature (lag 0). Figure 1 shows the results of the meta-analysis for all lags for the broad categories of respiratory disease admissions (ICD-9 codes 460–519) and for ischemic stroke (ICD-9 codes 433–436 admissions in those 65 years or older. For both disease categories the effect estimates diminished as the lag time increased. At lag 0 the percent change in respiratory disease per 10°F (5.6°C) was 2.0% (95% confidence interval (CI) = 0.7%–3.2%), while the percent change in ischemic stroke at lag 0 in the 65 and older group was 3.5% (CI = 1.5%–5.6%).

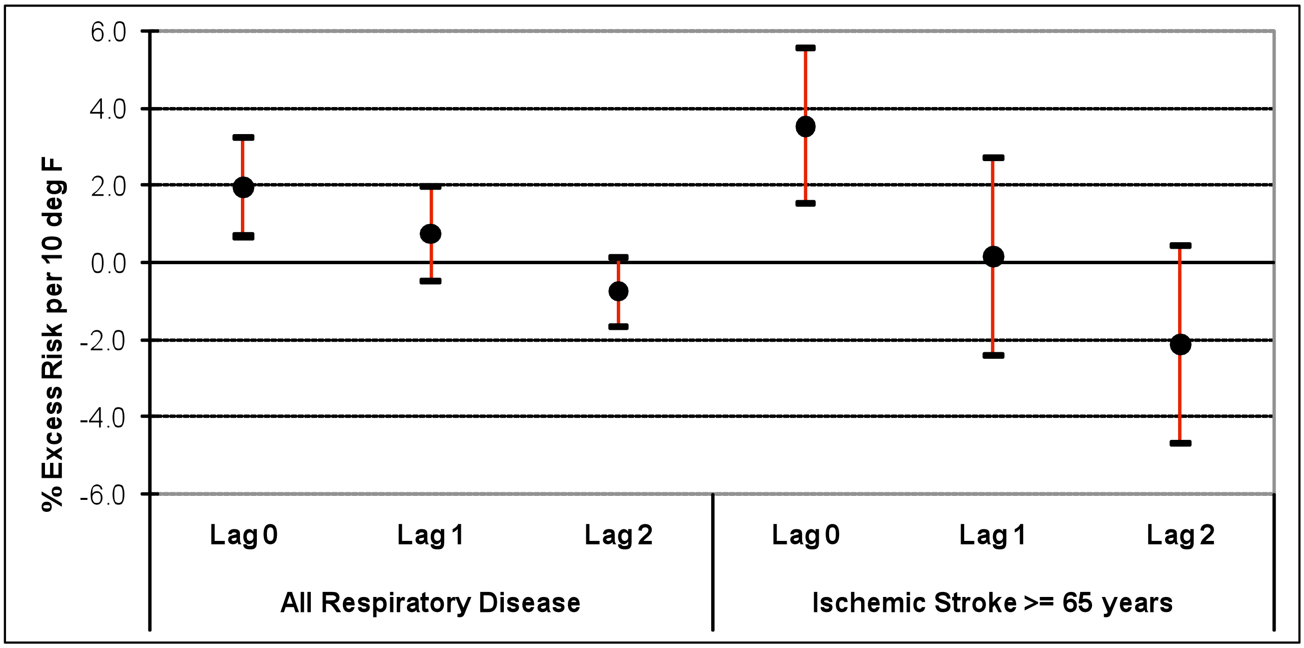

Figure 1. Meta-analysis for various lag periods for mean daily apparent temperature (per 10°F) and percent change in hospital admission for respiratory disease and ischemic stroke in nine California counties. Lag 0 = same day temperature; Lag 1 = temperature the previous day; Lag 2 = temperature two days previously

A similar pattern of decreasing effects with increasing lag periods was observed for other disease categories, such as dehydration and diabetes (data not shown). Therefore, all subsequent results are shown for lag 0. We did not find an association between temperature and all cardiovascular (ICD-9 codes 390–459) disease admissions in general or for ischemic heart disease, heart failure, or hemorrhagic stroke admissions in particular (Table 2). For the sub-categories of respiratory disease that we examined, only pneumonia was significantly related to apparent temperature (percent change = 3.7%; CI = 1.7%–5.7%). Neither asthma nor chronic obstructive pulmonary disease (chronic bronchitis or emphysema) was associated with apparent temperature.

Table 2 also shows results for other disease categories that we examined. Hospital admissions for diabetes, dehydration, acute renal failure, and heat stroke were all positively associated with increased temperature in our analysis. For example, the percent change associated with a 10°F increase in temperature was 7.4% (CI = 4.0%–10.9%) for acute renal failure. Heat stroke was strongly associated with temperature, although there were only 226 cases of heat stroke in the nine counties. The percent change in heat stroke associated with a 10°F increase in apparent temperature was 342.1% (CI = 155.4%–665.3%). Adding $PM_{2.5}$ to the base model reduced the effect estimates for all respiratory disease admissions to 0.8% (-0.3%–1.9%) and for all pneumonia admissions to 2.7%, but the latter remained significant (95% CI =0.6–4.9) (Table 2). With $PM_{2.5}$ in the model. the effect estimate increased for ischemic stroke in those 65 years or older decreased only slightly for diabetes and dehydration, and remained the same for acute renal failure.

Matching on ozone within 4 ppb had a similar effect on the estimates for all respiratory disease and all pneumonia, but the 95% confidence interval for the pneumonia estimate widened and included zero (Table 2). There was heterogeneity in the pneumonia results matched on ozone, with San Diego County and Santa Clara County each showing significant effect estimates of over 12% per 10°F increases in temperature. The effect estimates for ischemic stroke age 65 and older, and for diabetes, dehydration, and acute renal failure with all ages combined all increased slightly when the model was matched on ozone.

Although we did not find differences in effect estimates by gender or ethnicity, the effect of apparent temperature did differ by age for several of the outcomes we studied. Figure 2 shows the results for all respiratory disease and pneumonia by subgroups of age. For all respiratory diseases, the effects of temperature are highest for those under 5 years (percent change = 2.3%; CI = -0.5%–5.2%) and over 65 years (percent change = 3.0%; CI = 1.1%–5.0%). A similar pattern is seen with pneumonia, although hospital admission in the 19–64 year age group is also significantly associated with temperature.

Hospital admission for dehydration was significantly associated with apparent temperature in all age groups except those under age 5 years (Figure 3), with the highest effect estimate seen in those age 5 to 18 years (percent change = 19.7%; CI = 6.4%–34.7%). This same subgroup (age 5 to 18 years) was the only one to show an association between intestinal infectious disease admissions and apparent temperature (percent change = 21.3%; CI = 5.2%–39.8%) (Figure 3).

Figure 4 shows the results of the meta-analysis for diabetes and acute renal failure by age. The effect of temperature on diabetes admissions was significant in both the 19 to 64 year age group and in those ages 65 or greater, with the largest effect in the latter group. Acute renal failure showed a strong positive association with temperature only in the 65 or over age group (percent change = 10.7%; CI = 6.5%–15.2%).

Table 2. Meta-analysis results for apparent temperature (lag 0) and hospital admissions, adjusted by individual pollutant for nine California counties, 1999–2005. Percent change (95% CI) per 10°F using case-crossover approach.

Diagnosis	ICD-9 Code	Number of Cases	Base model: temperature plus day of week	Base model matched on Ozone within 4 ppb	Base model plus $PM_{2.5}$
Respiratory Diseases					
All respiratory disease	460–519	238,754	2.0 (0.7, 3.2)	0.9 (-1.6, 3.5)	0.8 (-0.3 , 1.9)
All pneumonia	480–486	90,290	3.7 (1.7, 5.7)	2.6 (-1.8, 7.2)	2.7 (0.6 , 4.9)
Asthma	493	28,944	-1.1 (-4.0, 1.9)		
Chronic Bronchitis or Emphysema	491–492	36,588	0.5 (-2.7, 3.8)		
Cardiovascular and Cerebrovascular Diseases					
All cardiovascular disease	390–459	503,585	-0.2 (-1.2, 1.0)		
Ischemic heart disease age 65+	410–414	94,359	1.1 (-0.4, 2.6)	0.5 (-3.6, 4.7)	1.2 (-0.8 , 3.3)
Acute myocardial infarction	410	57,231	-0.4 (-3.6, 2.9)		
Heart failure	428	82,034	-2.0 (-4.7, 0.7)		
All cerebrovascular disease	430–438	91,806	-0.3 (-2.3, 1.7)		
Hemorrhagic stroke age 65+	430–432	7,735	-9.9 (-14.2, 5.3)		
Ischemic stroke age 65+	433–436	55,131	3.5 (1.5, 5.6)	8.8 (4.9, 12.8)	5.2 (3 , 7.5)
Other diseases					
Diabetes	250	50,282	3.1 (0.4, 5.9)	4.2 (0.6 , 7.9)	2.8 (0.6 , 5.1)
Intestinal infectious disease	001–009	10,985	2.7 (-1.3, 7.0)		
Dehydration	276.5	31,235	10.8 (8.0, 13.6)	12.2 (5.1 , 19.8)	6.9 (1.5 , 12.6)
Acute renal failure	584	17,778	7.4 (4.0, 10.9)	8.6 (2.5 , 15.1)	7.4 (1.2 , 14)
Heat stroke	992	226	342.1 (155.4, 665.3)		

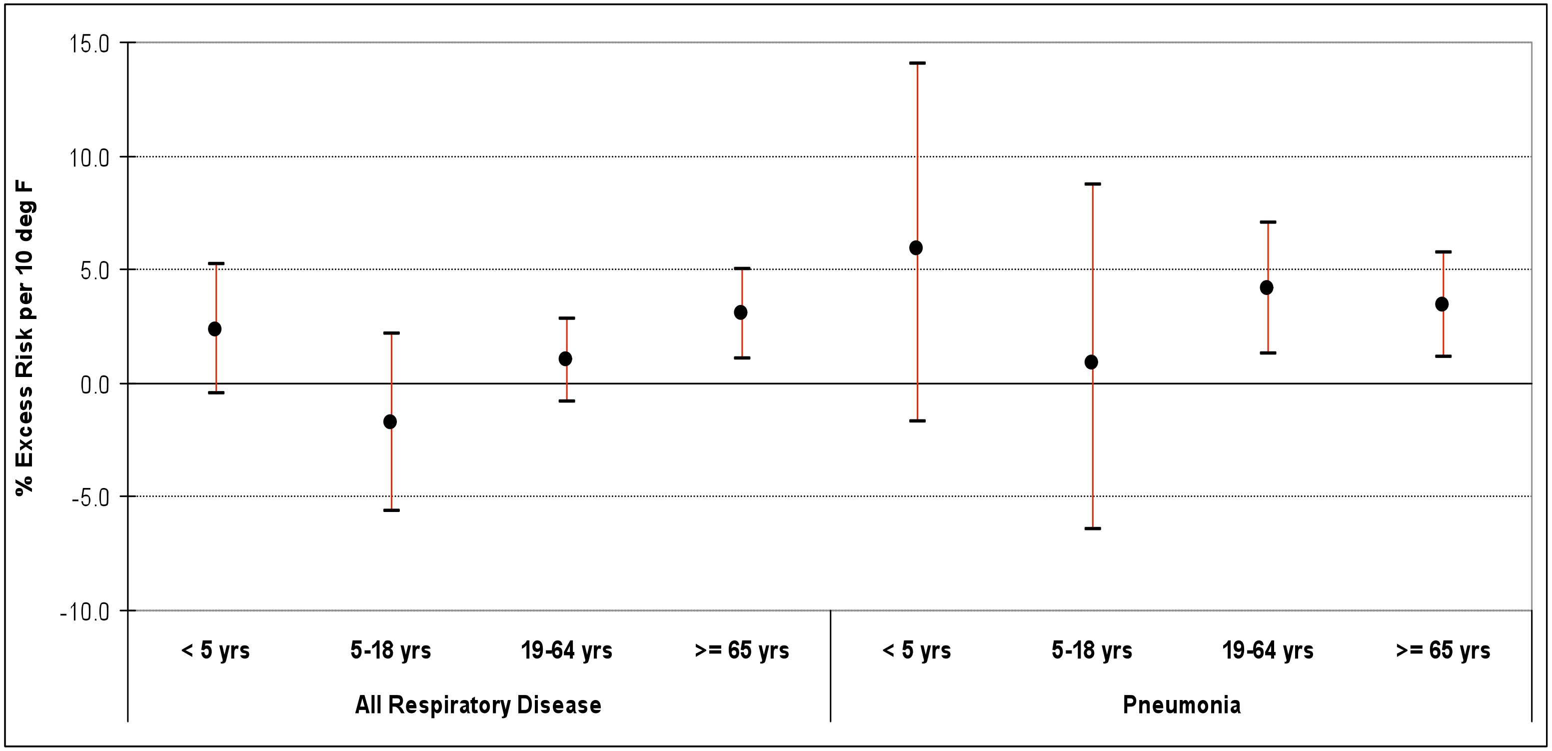

Figure 2. Meta-analysis for lag 0 (same day) mean daily apparent temperature (per 10°F) and percent change in hospital admission for all respiratory disease and for pneumonia, by age, in nine California counties

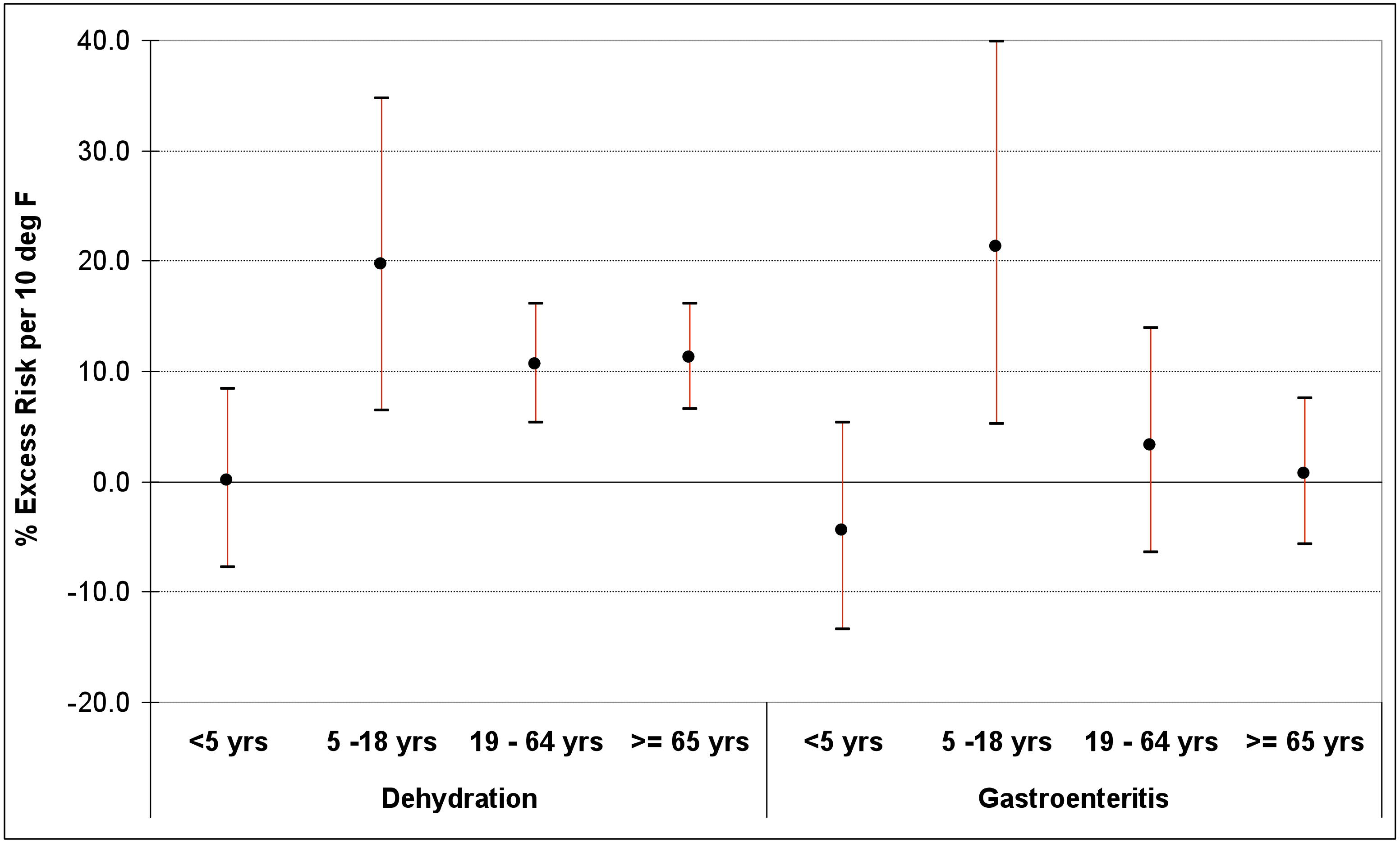

Figure 3. Meta-analysis for lag 0 (same day) mean daily apparent temperature (per 10°F) and percent change in hospital admission for dehydration and for infectious intestinal disease (gastroenteritis), by age, in nine California counties

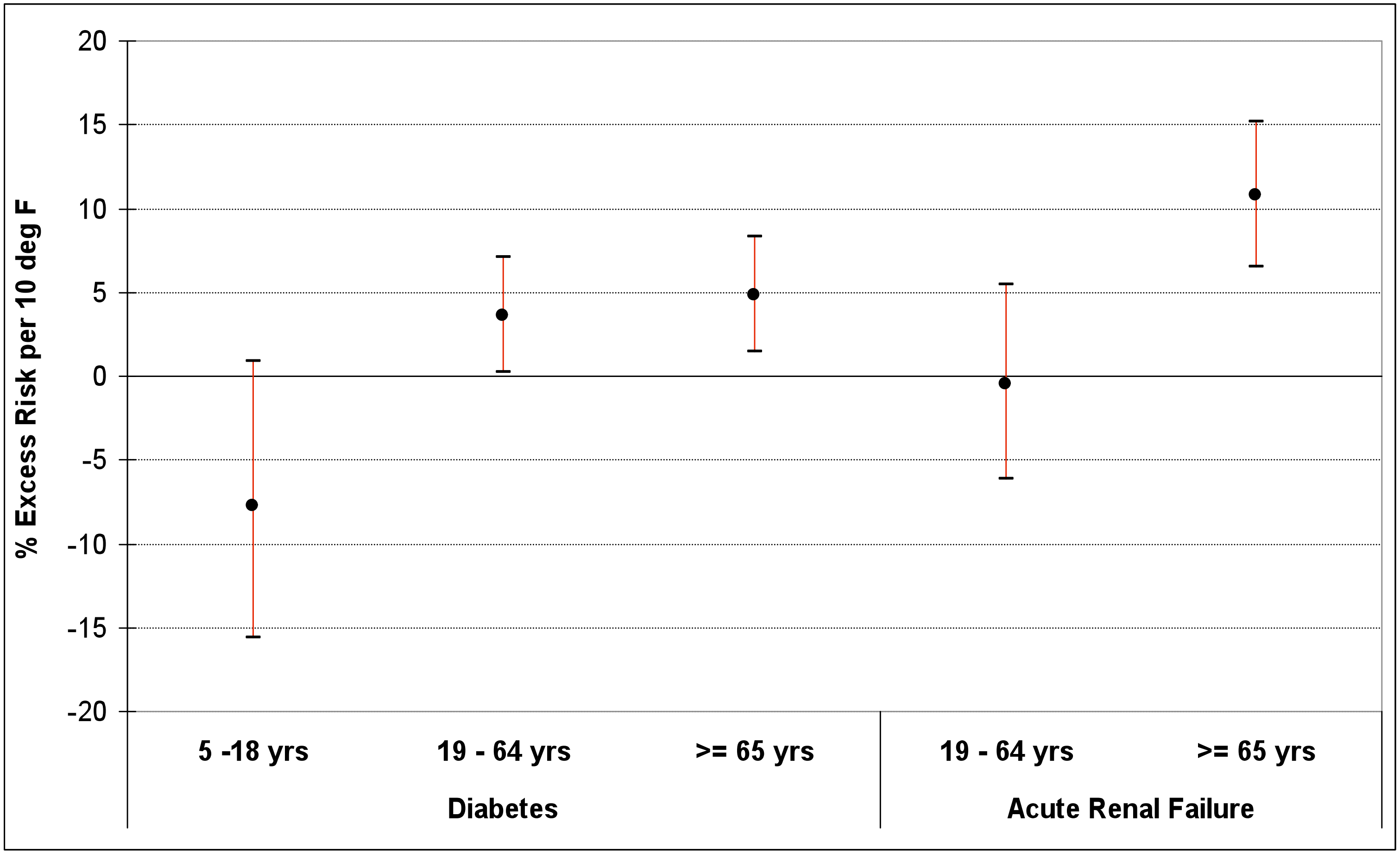

Figure 4. Meta-analysis for lag 0 (same day) mean daily apparent temperature (per 10°F) and percent change in hospital admission for diabetes and acute renal failure, by age, in nine California counties

4.0 Discussion

We found that diseases in several categories were related to increased same day apparent temperature in nine California counties from 1999–2005. These included heat stroke, dehydration and acute renal failure, diabetes, intestinal infectious disease, ischemic stroke, and respiratory disease. Among respiratory diseases, pneumonia showed the strongest association with increased apparent temperature. Although there was little difference in the associations by gender or ethnicity, we found that age modified the effect of temperature. The effect for respiratory disease was seen mainly in the under 5 age group and those 65 years and older, while a significant effect for ischemic stroke was only found in those over 65 years. The effect estimates for both dehydration and infectious intestinal diseases were highest in those in the 5- to 18-year-old category. Controlling for ozone and $PM_{2.5}$ reduced the effects of temperature on respiratory disease but did not change the effect estimates for the other diseases studied.

Our finding of a higher effect estimate in the younger and older age groups for some causes is consistent with our previous study of the effect of temperature on mortality in nine California counties (Basu and Ostro 2008). In this analysis of hospital admissions we found that the school age (5- to 18-year-old) group was most susceptible to the effects of temperature on dehydration and intestinal infectious disease. Other studies have found higher effects of air pollution in children who play sports (McConnell et al. 2002), and the effect of high temperature may have been more pronounced in this age group because they are more likely than adults to engage in outdoor activities during the warm months of the year.

Our finding of a greater effect of temperature on dehydration and intestinal infectious disease in the 5- to 18-year-old age category is consistent with outbreaks of foodborne illness such as *Salmonella enteritidis* occurring more frequently in the summer in schools and residential institutions (Gillespie et al. 2005).

In this study of hospital admissions we did not find effect modification by race/ethnicity or gender. Our previous study of temperature and mortality in the same nine California counties also did not find differences by gender (Basu and Ostro 2008), but it did find a higher effect of temperature on all-cause mortality in the Black racial/ethnic group compared with Whites and Hispanics. Hospital admissions may not be a completely accurate measure of temperature related morbidity in all racial/ethic groups because of possible differences in health insurance coverage. Further studies of temperature using emergency room visits as the measure of morbidity may find differences by race/ethnicity.

Our negative finding for asthma admissions is consistent with a study conducted in Greece, which has a similar climate to California (Nastos et al. 2008). They found that pediatric hospital admissions for asthma were positively correlated with cooling power, wind speed and relative humidity, but negatively correlated with an index that measures discomfort from high temperatures and relative humidity. The authors used the monthly number of hospital admissions as the dependent variable and monthly averages of the two temperature indexes as the independent variable. Therefore, they may not have captured associations of asthma with daily temperature variation during the summer months.

Our findings of an increase in pneumonia admissions are consistent with those seen in a study of the Chicago heat wave in July 1995 (Semenza et al. 1999). In that study the pneumonia excess was found when secondary diagnoses were analyzed, while our study examined the primary diagnosis. Reporting differences may have lead to our positive finding for pneumonia, as it is up to the admitting physician to determine primary versus secondary diagnosis. Consistent with our findings, a recent time-series study of hospital admissions in 12 European cities found a positive association for high temperature and all respiratory causes (ICD-9 codes 460-519) (Michelozzi et al. 2008).

In this study we did not find an effect of high temperature on hospital admissions for heart diseases, which is consistent with the findings of the recent European study (Michelozzi et al. 2008). However, studies of hospital admissions in other parts of the United States have found some associations. Morabito et al. (2005) found that myocardial infarction was associated with nine hours per day of severe discomfort caused by hot climatic conditions. A study of hospital admissions in elderly people in Denver (Koken et al. 2003) found that higher temperatures increased the risk of hospital admission for acute myocardial infarction and congestive heart failure, while decreasing the risk of admission for coronary atherosclerosis and pulmonary heart disease. Schwartz et al. (2004) found an effect of high temperature on hospital admissions for cardiovascular disease in 12 U.S. cities. The effect was smaller for admissions for myocardial infarction specifically. That study also found that there was a suggestion of harvesting at very high temperatures.

A study of hospital admissions for acute stroke in Scotland found that ischemic stroke was associated with increase in mean temperature during the preceding 24 hours (Dawson et al. 2008), while hemorrhagic stroke was not associated with increase in temperature. This is consistent with our findings of an effect for ischemic, but not hemorrhagic stroke. Since heat has been shown to increase blood viscosity and clotting, it is plausible that heat would not increase hemorrhagic stroke (Keatinge et al. 1986).

This current study has many strengths. First, misclassification of exposure was less likely than in previous studies using county averages of temperature because our study was limited to subjects whose residential zip codes were located within 10 kilometers of a temperature monitor, and the nearest monitor was chosen to measure daily temperature and humidity. Second, we were able to examine many outcomes and population sub-groups. Third, use of the case-crossover design accounts for individual level known and unknown confounders because each person acts as his own control (methods section). Finally, we were able to examine possible confounding effects of air pollution on the positive associations between temperature and morbidity we found in this study. In this study, matching on ozone reduced the effect of temperature on respiratory disease in the combined meta-analysis. However, there were two coastal counties where matching on ozone actually increased the effects of heat.

There were also some limitations to this study. Use of hospital admission data limits the amount of individual level data. For example, there was no information on air conditioning. However, air conditioning may be less of a confounder in California, since many coastal homes do not have it. We did not know where people spent most of their time, and work and leisure patterns affect actual exposure to high temperatures. Since we used the zip code centroid to determine distance from the residence to the temperature monitor, the actual residences of some subjects may have fallen outside the 10 kilometer buffer of the assigned monitor. Therefore time activity patterns and exposure assignment based on zip code centroid instead of residence may have lead to misclassification of exposure for some study subjects. We do not expect such exposure misclassification to be differential with respect to the discharge diagnoses, however. Therefore, the results presented in this study are probably an underestimate of the actual temperature effects. For example, the association of temperature with dehydration was somewhat lower than would be expected given the direct relationship of this outcome with heat. Finally, there may be variation among hospitals and physicians in which diseases are assigned to primary and secondary diagnoses and in the classification of diseases.

Even without extremes in apparent temperature, we observed an association between temperature and hospital admissions in California. Reducing heat exposure through air conditioning use and mitigating the effects of heat through adequate hydration during hot weather are important steps in reducing heat-related morbidity.

5.0 References

Anderson, H. R., R. W. Atkinson, J. L. Peacock, M. J. Sweeting, and L. Marston. 2005. "Ambient particulate matter and health effects: Publication bias in studies of short-term associations." *Epidemiology* 16**:**155–163.

Basu, R., F. Dominici, and J. M. Samet. 2005. "Temperature and mortality among the elderly in the United States: A comparison of epidemiologic methods." *Epidemiology* 16**:**58–66.

Basu, R., W. Y. Feng, and B. D. Ostro. 2008. "Characterizing Temperature and Mortality in Nine California Counties." *Epidemiology* 19**:**138–145.

Basu, R., B. D. Ostro. 2008. "A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California." *Am J Epidemiol* 168**:**632–637.

Dawson, J., C. Weir, F. Wright, C. Bryden, S. Aslanyan, K. Lees, et al. 2008. "Associations between meteorological variables and acute stroke hospital admissions in the west of Scotland." *Acta Neurol Scand* 117**:**85–89.

DerSimonian, R., and N. Laird. 1986. "Meta-analysis in clinical trials." *Control Clin Trials* 7**:**177–188.

Garssen, J., C. Harmsen, and J. de Beer. 2005. "The effect of the summer 2003 heat wave on mortality in the Netherlands." *Euro Surveill* 10**:**165–168.

Gillespie, I. A., S. J. O'Brien, G. K. Adak, L. R. Ward, and H. R. Smith. 2005. "Foodborne general outbreaks of Salmonella Enteritidis phage type 4 infection, England and Wales, 1992–2002: Where are the risks?" *Epidemiol Infect* 133**:**795–801.

Keatinge, W. R., S. R. Coleshaw, J. C. Easton, F. Cotter, M. B. Mattock, and R. Chelliah. 1986. "Increased platelet and red cell counts, blood viscosity, and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis." *Am J Med.* 81**:**795–800.

Koken, P. J., W. T. Piver, F. Ye, A. Elixhauser, L. M. Olsen, and C. J. Portier. 2003. "Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver." *Environ Health Perspect.* 111**:**1312–1317.

Kovats, R. S., H. Johnson, and C. Griffith. 2006. "Mortality in southern England during the 2003 heat wave by place of death." *Health Stat Q.* 6–8.

Le Tertre, A., A. Lefranc, D. Eilstein, C. Declercq, S. Medina, M. Blanchard, et al. 2006. "Impact of the 2003 Heatwave on All-Cause Mortality in 9 French Cities." *Epidemiology* 17**:**15.

Levy, D., T. Lumley, L. Sheppard, J. Kaufman, and H. Checkoway. 2001. "Referent selection in case-crossover analyses of acute health effects of air pollution." *Epidemiology* 12**:**186–192.

McConnell, R., K. Berhane, F. Gilliland, S. J. London, T. Islam, W. J. Gauderman, et al. 2002. "Asthma in exercising children exposed to ozone: A cohort study." *Lancet* 359**:**386–391.

McGeehin, M. A., and M. Mirabelli. 2001. "The Potential Impacts of Climate Variability and Change on Temperature-Related Morbidity and Mortality in the United States." *Environ Health Perspect.* 109 Supplement 2**,** 185–189.

Michelozzi, P., G. Accetta, M. De Sario, D. D'Ippoliti, C. Marino, M. Baccini, et al. 2008. "High Temperature and Hospitalizations for Cardiovascular and Respiratory Causes in 12 European Cities." *Am J Respir Crit Care Med.*

Morabito, M., P. A. Modesti, L. Cecchi, A. Crisci, S. Orlandini, G. Maracchi, et al. 2005. "Relationships between weather and myocardial infarction: A biometeorological approach." *Int J Cardiol.* 105**:**288–293.

Nastos, P. T., A. G. Paliatsos, M. Papadopoulos, C. Bakoula, and K. N. Priftis. 2008. "The effect of weather variability on pediatric asthma admissions in Athens, Greece." *J Asthma* 45**:**59–65.

Schwartz, J., J. M. Samet, and J. A Patz. 2004. "Hospital admissions for heart disease: the effects of temperature and humidity." *Epidemiology* 15**:**755–761.

Semenza, J. C. 1999. "Acute renal failure during heat waves." *Am J Prev Med.* 17**:**97.

Semenza, J. C., J. E. McCullough, W. D. Flanders, M. A. McGeehin, and J. R. Lumpkin. 1999. "Excess hospital admissions during the July 1995 heat wave in Chicago." *Am J Prev Med.* 16**:**269–77.

Stafoggia, M., F. Forastiere, D. Agostini, A. Biggeri, L. Bisanti, E. Cadum, et al. 2006. "Vulnerability to heat-related mortality: A multicity, population-based, case-crossover analysis." *Epidemiology* 17**:**315–323.